Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Solar Energy 78 (2005) 19–22
SOLAR ENERGY
www.elsevier.com/locate/solener

Solar cookers—part-II—cooking vessel with central annular cavity

A.V. Narasimha Rao [a,*,1], S. Subramanyam [b]

[a] Department of Mechanical Engineering, National Institute of Technology, Warangal 506 004, India
[b] 2-7-444, Excise Colony, Subedari, Warangal 506 004, India

Received 23 February 2004; received in revised form 29 July 2004; accepted 29 July 2004
Available online 11 September 2004

Communicated by: Associate Editor Michael Grupp

Abstract

Cooking vessels used in a solar cooker must be able to transfer the heat trapped in the cooker effectively to the food material. In the preceding paper (Part-I) the advantage of keeping the vessel on lugs was discussed. In the current paper the performance of a cooking vessel with a central annular cavity kept on lugs is discussed. The experiments were conducted for several days using water and thermic fluid as working medium. The studies indicated that the cooking vessel with central annular cavity on lugs performs much better than the conventional vessel kept on the floor of the cooker. The conventional vessel is considered to be the benchmark for the purposes of comparison.

Keywords: Box-type solar cooker; Intermittent azimuthal tracking; Cooking vessel with a central annular cavity; Cooking vessel on lugs

1. Introduction

A significant amount of work was carried out since late 19th century by several investigators on different designs of solar cookers and their performance improvement. A detailed review of this work was presented in our preceding paper (Part-I). Surprisingly, not much attention was paid to the shape and size of the cooking vessel. In our paper (Part-I) it was demonstrated experimentally that a cooking vessel kept on lugs improves the performance of the cooking vessel significantly when compared to the identical vessel kept on the floor of the cooker (Narasimha Rao and Subramanyam, 2003). In the present paper, the performance of a cooking vessel with central annular cavity on lugs is demonstrated experimentally. It is observed that the central annular cavity increases the effective area of heat transfer to the water and hence reduces the time of cooking. The hot air circulates through the cavity of the vessel reducing the heat transfer path length considerably. The principle of operation on which the concept of the vessel with annular cavity was derived is now described.

* Corresponding author. Tel.: +91 251 4 410121; fax: +91 251 4 409304.
E-mail address: avnrao5@yahoo.co.in (A.V. Narasimha Rao).
[1] ISES member.

0038-092X/$ - see front matter
doi:10.1016/j.solener.2004.07.007

Consider a cooking vessel containing food material, heated from the sides. After the initial phase when the excess or free water is evaporated or absorbed, the food material can be described as a semi solid medium. In such a case a temperature gradient is established in the food. The temperature will have a maximum value at the wall of the cooking vessel. It decreases as the distance from the wall increases and may reach a level, which is insufficient to carry forward the cooking process. This deficiency can be overcome by providing a heat source from the opposite direction. The annular cavity provides such a heat source. A classic example in traditional Indian cooking is that of a VADA. An annular hole in the thick center ensures that complete frying takes place in the interior of the thickest portion.

Even if the temperature at all points are sufficient for cooking it is easily seen that the second source of heat will speed up the cooking.

2. Description of the solar cooker and the vessel

Fig. 1 shows a sketch of a box-type solar cooker. The cooker consists of a square aluminum tray constructed of a 1 mm thick sheet. The sides and bottom of the tray are encased in a box made of sheet metal. The gap between the tray and the casing is filled with the glass wool to provide thermal insulation. The tray is provided with a movable double glass cover hinged to one side of the casing at the top. A plane glass mirror, encased in a sheet metal shell is fitted to serve as a reflector. This serves as a cover for the double glass glazing when the cooker is not in use. The conventional cooking vessels are cylindrical in shape and have flat base and usually are made of aluminum. The vessels are provided with tight fitting flat covers. The tray and outside of the vessels are painted with dull black paint. The conventional cooking vessel and a cooking vessel with central annular cavity are depicted in Fig. 1. The conventional cooking vessel is cylindrical in shape (ϕ = 220 mm and height = 62.5 mm) and has a flat base. It has a tight fitting flat cover. Another cooking vessel with the same outer diameter and with a central annular cavity (ϕ = 55 mm) is used for comparison and the details of this vessel are depicted in Fig. 2

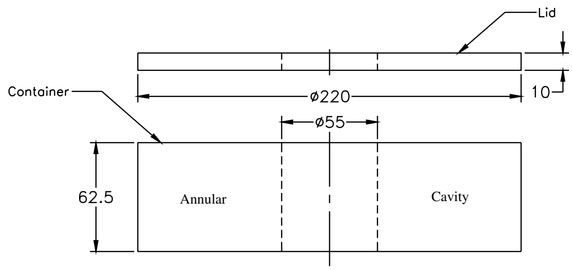

Fig. 2. Container and lid of a cylindrical cooking vessel with a central annular cavity.

Fig. 2 illustrates the cooking vessel with central annular cavity. The vessel consists of two parts; (i) a container and (ii) a lid. The lid is a circular aluminum plate with its circular edge bent downwards. The plate has a hollow concentric cylindrical projection (φ = 55 mm) downwards at the center. The container consists of a cylindrical vessel with an upward projecting hollow concentric cylinder (φ = 55 mm) at the center of the vessel. The food material to be cooked can be loaded in the annular cavity between the inner wall of the vessel and the outer wall of the cylindrical projection prevailing in the vessel. The lid can be press fit snugly, over the outer edge of the vessel and also on the cylindrical projection in the container of the vessel. Air can pass through the central cylindrical

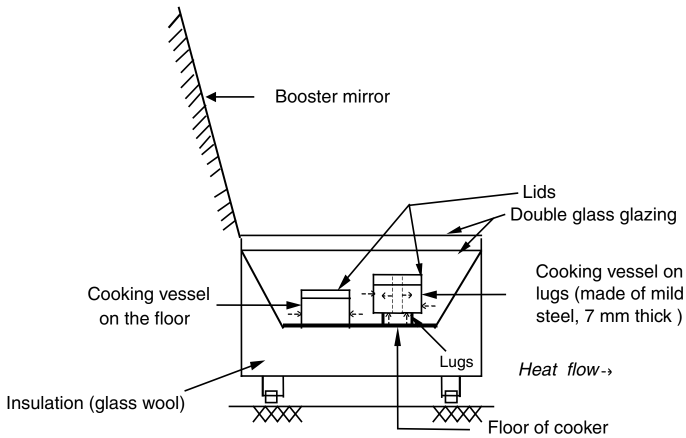

Fig. 1. Box-type solar cooker with a conventional cylindrical cooking vessel on the floor of the cooker and another vessel with central annular cavity kept on three lugs spaced at 120°. The process of heat flow into the water contained in both the cooking vessels is indicated.

hole of the vessel, right from bottom to top, when the lid is press fit to the container.

3. Mechanism of heat flow to the food

Because the interior of the cooker and the cooking vessels are painted black they absorb the insolation and get heated. The glass covers prevent heat flowing out of the cooker, as they are opaque to the infrared radiation emitted by the vessels and interior of the cooker. The metal surface, which gets hot, in turn heats the air present inside the cooker. Hence the temperature inside the cooker reaches a value at which the input and losses balance each other. Because the cooking vessel with central annular cavity is placed on the lugs the hot air circulates freely through the gap between the bottom surface and the floor of the cooker and also through the central cylindrical hole in the vessel. The central cylindrical hole reduces the heat transfer path length and facilitates better transfer of heat to the water/thermic fluid kept in the vessel. The enhanced area of heat transfer and the improved circulation of the hot air through the central cylindrical hole are expected to bring down the cooking time in the cooking vessel with central annular cavity. This is amply borne out by experiments (see Fig. 3). The pattern of heat flow into the water, which is kept in the annular cavity of the vessel, is illustrated in Fig. 1.

4. Experiment

The arrangement of vessels in a solar cooker loaded with water or thermic-fluid during heating tests is shown in Fig. 1. The conventional cylindrical cooking vessel is kept on the base of the cooker and the other cooking vessel with central annular cavity is kept on three mild steel lugs of 7 mm height and 10 mm diameter placed at 120° spacing. Each of the vessels is loaded with a fixed mass of water/thermic-fluid. The total mass of water/thermic-fluid and initial temperature of water/thermic-fluid are noted. The temperature of the water in each of the vessels, ambient temperature and insolation values are recorded at preset intervals of time using a distributed data acquisition system (DDAS). The DDAS consists of a data scanner, data controller and a PC with suitable software. Water/thermic-fluid temperatures in each of the two vessels are measured by a copper–constantan thermocouple, whose hot junction is fixed to be inside the water/thermic-fluid by drilling a small hole through the lid, passing the thermocouple through the hole and then sealing the hole. Hence the vessel inside the cooker remained covered by their lids during the course of the tests. The solar cooker is not opened during the course of the test. The cooker is tracked hourly once in order to collect the maximum amount of insolation. The tracking is done by rotating the cooker azimuthally in such a way that the azimuth of the mirror normal and the sun are equal and the reflected rays from the mirror illuminate the entire cooker aperture and the aperture alone.

The temperature–time history of the water/thermic-fluid in the cooker vessel is recorded in preset intervals of time for several days at the Solar Energy Laboratory of the National Institute of Technology, Warangal (latitude = 17.95°N, longitude = 79.5°E and elevation = 275 m above the mean sea level), India. Concurrently the global and diffuse components of insolation are also recorded with the help of pyranometers and a dual channel solar integrator.

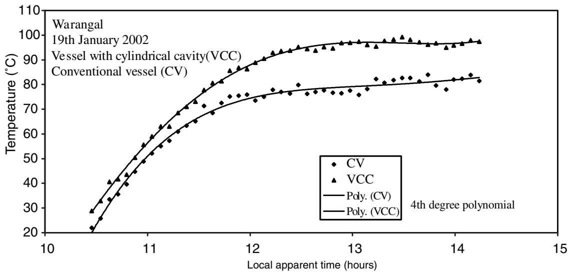

Fig. 3. Temperature–time history of water in the conventional cooking vessel kept on the floor of the box type solar cooker and that in another cooking vessel with central cylindrical cavity on the mild steel lugs of 7 mm height. The experiment was conducted on 19th January 2002 at Warangal (latitude = 17.95°N, longitude = 79.5°E and elevation = 275 m above the mean sea level).

5. Results and discussion

Observations were recorded over a number of days. A typical temperature–time history of the water in both the cooking vessels are shown in Fig. 3. It is evident from the figure that the temperature of the water kept in the vessel with central annular cavity, supported on lugs, achieves maximum nearly 20 to 25 min earlier when compared to that in the vessel kept on the floor. The temperature difference is as high as 20 °C. It is a clear indication that the cooking would take place faster in the vessel on lugs. The reduction in cooking time is due to the following factors; (i) the vessel is kept on the lugs and (ii) the enhanced heat transfer surface area because of the central annular cavity. The actual cooking tests have confirmed this.

6. Conclusion

When the vessel with central annular cavity is placed on lugs in the cooker interior, the hot air circulation through the gap between the bottom of the cooking vessel and the floor of the cooker and through the central annular cavity improved the heat transfer to the water in the vessel and resulted in the reduction of the cooking time. This type of vessel is recommended for use in solar cookers.

Acknowledgments

Authors thank the University Grants Commission, New Delhi, for providing financial assistance for carrying out the work. Authors wish to express their gratitude to the Director, National Institute of Technology, Warangal, for providing facilities to carry out the experimental work. Author Narasimha Rao wishes to thank Dr. Mitiku Haile (President), Mekelle University, Mekelle, Ethiopia, for providing facilities for preparation of the manuscript and also for his encouragement for the research in the field of renewable energy. Authors wish to express their thanks to Mr. Mulualem Andarge for preparing the drawings.

Reference

Narasimha Rao, A.V., Subramanyam, S., 2003. Solar cookers Part-I cooking vessel on lugs. Solar Energy 75, 181–185.